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THOMAS HALL ROBINSON O'NEILL

FORECASTING 24-HOUR ISALLOHYPTIC CENTERS
AT THE 500 MB. LEVEL

by

Thomas Hall Robinson O'Neill

Lieutenant Commander, United States Naval Reserve

Submitted in partial fulfillment
of the requirements
for the degree of
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PREFACE

In meteorology, as in many other sciences, the increasing application of statistical methods has produced valuable empirical results as well as aiding in the development of laws explaining natural phenomena.

It is the purpose of this investigation to test the significance of some existing qualitative empirical rules for forecasting high-level pressure changes and, further, to develop objective quantitative techniques, if possible.

This paper was prepared at the U. S. Naval Postgraduate School, Monterey, California, during the first half of 1954.

The writer wishes to express appreciation to Professor George J. Haltiner of the Aerological Engineering Staff for his valuable assistance and guidance in the preparation of this paper.

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LIST OF ILLUSTRATIONS

TABLE OF SYMBOLS AND ABBREVIATIONS

X_i	Parameters of the 500 Mb. Constant Pressure Chart - See Table 1. ($i = 1$ to 11)
Δn	200 ft. contour spacing (Deg. Latitude).
$(\ )_T$	Quantity measured at the trough line.
$(\ )_I$	Quantity measured at the inflection point.
V_{gs}	Geostrophic wind.
Φ	Degrees of latitude.
R_i	Parameters of the 500 Mb. Height Change Chart - See Table 1. ($i = 1$ to 8)
Y_1	Values obtained from Figure 3 graph.
Y_2	Values obtained from Figure 4 graph.
r	Correlation coefficient.
S_j	Standard error of estimate. (j = dependent variable).

CHAPTER I

INTRODUCTION

A primary step in the development of the weather forecast is the prediction of the pressure field both aloft and at the surface. From the prognostic pressure field, the atmospheric circulation and the subsequent air mass movements with associated frontal boundaries may then be determined. The prognostic sequence consequently leads to the forecast of the various weather phenomena in time and space.

Even for the experienced forecaster, it is difficult to visualize the future positions and the complexity of the changing pressure systems without the aid of the prognostic chart. This chart is an essential tool for eliminating forecasts of inconsistent pressure gradients and irregular pressure changes, particularly when the intensity of the systems are increasing or decreasing. Therefore, an accurate prognostic chart is inherent in a reliable forecast.

With the ever increasing ceilings and operational altitudes of the present-day aircraft the aerologist must focus greater attention on the high level charts. The transport squadrons frequently operate their long range flights at the 500 mb. level and therefore are interested in the forecast of the pressure pattern at this level for their routes. The level of 500 mb. is not so high that data is scarce, whereas at higher levels the lack of data is common due to radiosonde transmission failures. The 500 mb. level, being approximately at the mid-point of the atmosphere, is also representative of

the mean atmospheric flow. Further, accurate prognosis of the 500 mb. level leads to better surface prognostic charts. It is principally for these reasons that the 500 mb. chart was selected for study.

In a discussion of prognostic analysis, O'Connor [1] formulates qualitative forecasting rules relating the wind velocity field aloft to pressure changes. The principal rules are embodied in the following statements and are classified into various cases for investigation:

> <u>Case I.</u> Divergence and upper height falls are associated with high speed winds approaching weak contour gradients which are cyclonically curved.
>
> <u>Case II.</u> Convergence and upper height rises are associated with low speed winds approaching straight or cyclonically curved strong contour gradients.
>
> <u>Case III.</u> Convergence and upper height rises are associated with high speed winds approaching anticyclonically curved weak contour gradients.

The purpose of the investigation was to determine whether contour rise or fall areas were associated with each case and then to investigate the cases separately for quantitative forecast rules. The period of 24 hours was selected for the time interval and 24 hour isallohyptic centers were used as the measure of the associated rise or fall area for each case.

The first phase of the investigation showed conclusively that 24 hour isallohyptic rise or fall centers were associated with the contour patterns in accordance with the statement of each case. The association of the isallohyptic center with each contour pattern was determined on the basis of the proximity of the rise or fall height change center for the following 24 hours to the mid-point of the high speed wind contour channel at the trough or ridge line.

The investigation was then continued for a determination of a quantitative forecast technique for the 24 hour height change centers under the selected situations. Various parameters, chosen on the 500 mb. chart, were combined by a graphical technique of multiple correlation to determine whether a sufficient relationship existed for a forecast tool. Similar techniques were successfully employed by Brier [2] and Thompson [3] for predicting the occurrence of precipitation in particular areas. George [4] also utilized this correlation method in developing charts for forecasting cyclogenesis at the surface under different types of flow aloft.

The major portion of the investigation was confined to Case I since, if the forecasting techniques were successful for that contour pattern, it was felt that the parameters correlated would have significance in the remaining two cases. However, this was not true and one of the principal conclusions of the investigation was that different forecasting techniques should be applied under each selected situation.

The magnitude, direction, and displacement of the isallohyptic center were treated separately as the dependent variable and will individually be the subject of the following chapters. The forecast of these variables was the ultimate goal of the investigation for with an accurate forecast of the magnitude, direction and displacement of the 24 hour isallohyptic centers, the main ingredient to the preparation of the prognostic chart has been determined.

CHAPTER II

PROCEDURE AND TECHNIQUE

1. Area Selection and Sources of Data.

The geographical area selected was from the western boundary of North America and extending eastward to cover the greater part of the European Continent. The selection of the area was based on the density of reporting stations, and oceanic areas were avoided where observational data were lacking.

For original data the period of January to December 1949 was selected. From the 500 mb. charts of the Northern Hemisphere Daily Synoptic Weather Map Series [5] the contour patterns of each case were determined and the parameter data recorded. For the same period the 500 Mb. Height Change Charts [6] provided the magnitude, direction and displacement of the isallohyptic centers.

In the test cases the period of July to December, 1950 was selected for independent correlation. Also under Case I additional data for a wintertime situation, including all isallohyptic fall centers, was taken from the 500 Mb. Height Change Charts for the period December 1949 to February 1950.

2. Case I and Selection of Parameters.

The samples of Case I consisted of areas where high speed winds at the inflection point were approaching weaker winds in the downstream trough. In Cases II and III, as well as in this case, data were selected from a single contour channel within the jet stream.

In general, the wind observations were not shown on the charts at the selected points so that the strength of the contour gradient at the inflection point and at the trough line were the principle parameters in defining the samples. Situations were excluded (1) where the curvature was questionable as to being definitely cyclonic or anticyclonic from the inflection point to the trough or ridge line, (2) if the wind reports and contour gradients were in disagreement, and (3) in areas where analyses for both the 500 mb. level and the 500 mb. height change chart were unreliable due to paucity of reports.

For Case I, O'Connor explains the fall area by the coriolis force of the high speed winds exceeding the balancing forces when entering a region of weaker pressure gradient. The air parcels are deflected to the right penetrating higher pressure and are slowed down until they are in balance with the weaker pressure gradient. The resulting transversal divergence outweighs the longitudinal convergence and produces pressure falls generally to the left of the particle trajectory. The cyclonically curved contours accentuate this effect. However, this physical explanation of Case I and subsequent cases was not a consideration in the investigation.

For the samples of Case I (and similarly for all three cases) parameters were selected for the development of an objective forecast technique. A few of the parameters are illustrated in Figure 1 and the definitions of all the parameters are given in Table 1.

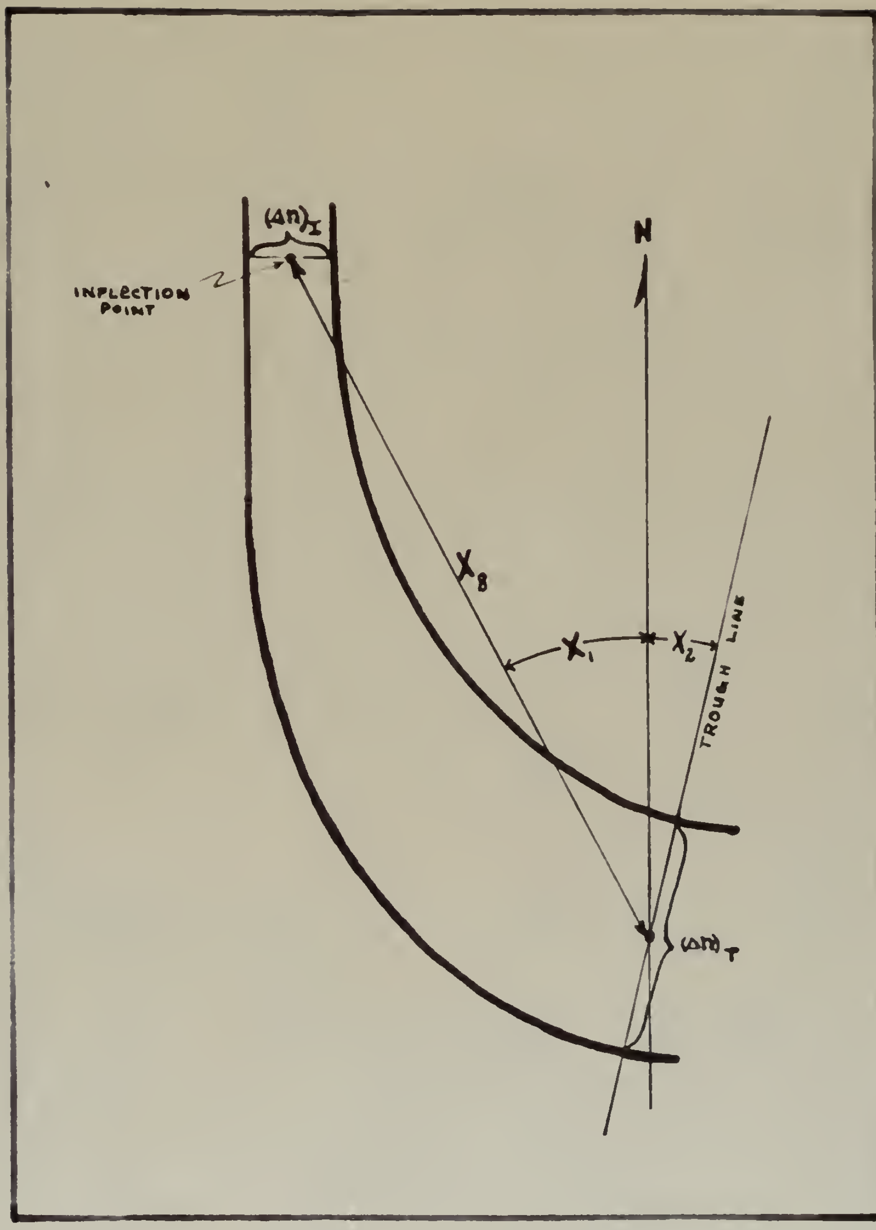


FIGURE 1

TABLE 1

DEFINITIONS OF PARAMETERS

Parameters of the 500 Mb. Constant Pressure Chart

X_1 Direction of the inflection point from the mid-point of the trough line or the mid-point of the ridge line from the inflection point within the selected contour channel.

X_2 The tilt of the trough (ridge) line.

X_3 Wind direction at the inflection point.

X_4 Temperature difference over a 10 degree latitude distance centered at the inflection point and perpendicular to the wind flow at the inflection point.

X_5 The difference of the 200 ft. contour spacing at the inflection point and the trough (ridge) line,

$$(\Delta n)_T - (\Delta n)_I \; .$$

X_5' X_5 corrected for latitude,

$$(\Delta n)_T / \sin \Phi_T - (\Delta n)_I / \sin \Phi_I \; .$$

X_5'' A measure of the geostrophic wind difference at the inflection point and at the trough (ridge) line,

$$1/(\Delta n)_T \sin \Phi_T - 1/(\Delta n)_I \sin \Phi_I \quad \text{or}$$

$$(V_{gs})_T - (V_{gs})_I = 71.6 \; X_5'' \; .$$

X_6 Temperature difference at the inflection point and the trough (ridge) line.

X_7 Radius of curvature measured at the trough (ridge) line.

X_8 Distance in degrees latitude of the inflection point to the mid-point of the trough (ridge) line within the selected contour channel.

X_9 A measure of the geostrophic wind at the inflection point,

$$1/(\Delta n)_I \sin \Phi_I .$$

X_{10} The difference of the wind direction at the inflection point and the trough (ridge) line.

X_{11} The geostrophic wind difference at the inflection point and at the trough (ridge) line as determined from the geostrophic wind scale.

Parameters of the 500 Mb. Height Change Chart

R_1 Magnitude of the isallohyptic center for the following 24 hours.

R_2 Direction of the isallohyptic center for the following 24 hours as measured from the mid-point of the selected contour channel at the trough (ridge) line of current map.

R_3 Direction of the isallohyptic center for the following 24 hours from the current position of the center.

R_4 Displacement of the isallohyptic center for the following 24 hours as measured from the mid-point of the selected contour channel at the trough (ridge) line of current map.

R_5 Displacement of the isallohyptic center for the following 24 hours from the current position of the center.

R_6 Magnitude of the isallohyptic center for the past 24 hours.

R_7 Direction of the isallohyptic center for the past 24 hours.

R_8 Displacement of the isallohyptic center for the past 24 hours.

From the 60 samples of Case I preliminary graphs of the parameters were constructed for comparison. The graphs indicated that some relationship existed among several of the parameters, as shown in Plate I. The establishment of such a relationship among these parameters influenced the subsequent combination with other parameters in the development of an objective forecast technique. The correlations* of these parameters are given in Table 2, and the multiple relationship of X_1, X_2 and X_3 is illustrated in Plate II.

TABLE 2

CORRELATIONS OF SEVERAL PARAMETERS

Parameter	Parameter	Correlation
X_1	X_2	0.824
X_1	X_3	0.636
X_2	X_3	0.420
X_7	X_8	0.448

3. Case II and Case III.

Both Case II and Case III are stated as being associated with contour rises. For Case II situations were selected where weak winds were approaching cyclonically curved stronger gradient. As in Case I a single contour channel selected within the jet stream was the basis of the sampling.

* Unless specifically stated otherwise, correlation will be that derived for a linear relation.

O'Connor accounts for the rise areas of Case II by the low speed winds that, entering an area of stronger gradient, are subject to an unbalanced force toward the left due to the weaker coriolis force. Contour rises result from the deflection of the subgradient winds towards lower pressure.

For Case III sampling was made where high speed winds were approaching sharply curved ridges. The overshooting of high speed air in the ridge is the explanation by O'Connor in Case III. Because of centrifugal forces the parcels of air cannot maintain the curvature of the contours in the ridge and, subsequently, their trajectory is directed toward low pressure downstream. The result is height rises in the area of overshooting winds.

4. General Graphical Technique.

Multiple correlation by graphical methods has been discussed by several authors as mentioned in the previous chapter and is treated in detail by Ezekiel [7] as a short-cut method for determining regression lines and curves. The procedure was to consider the parameters in pairs and construct scatter diagrams. To each of the points on the diagram the corresponding values of the dependent variable (forecast item) were plotted. From these plotted values, isolines were drawn and the regularity of the pattern was studied for its usefulness. The results of the isoline pattern yields a single derived variable and from any number of such sets other derived variables may be combined to obtain a final forecast value.

The combination of all the parameters with each of the dependent variables would be a lengthy process not within the time limit of

this paper. A lengthy reference search assisted very little in determining a preferred combination. Therefore, in the procedure of combining the pairs of observations, parameters were chosen that best described the specific case or were preferred by forecasters using subjective techniques.

CHAPTER III

MAGNITUDE OF THE ISALLOHYPTIC CENTERS

1. Case I.

Case I states that contour falls will occur as the results of the high speed winds entering weaker contour gradient of the trough. Since the areas of these falls should be reflected on the 24 hour height change chart, the isallohyptic centers were taken as a measure of the magnitude of this fall. The value at the center was chosen mainly for convenience of measurement from the height change charts and also because the history of the change centers is generally maintained where upper level prognosis is a routine procedure.

The association of isallohyptic fall centers with the contour patterns of the 60 samples of Case I, which with 95% confidence contain 94% of the population between the sample extremes, verified without exception. The fall areas were at a shorter distance from the mid-point of the selected contour channel in the trough line than were any rises in the area. In general, within the immediate vicinity of the trough and its subsequent movement, contour rises were non-existent because the region of contour falls extended over the area.

Although the variable, X_5'' (a measure of the geostrophic wind difference at the inflection point and the trough line), was not anticipated to show a large significant correlation singly with contour falls, a correlation was computed to determine the effect

of the wind field on the associated fall centers, as illustrated in Figure 2. In fact the derived correlation coefficient of 0.251 is not significant at the 5% level and, therefore, the probability of a close relationship of the two variables is small.

To develop an objective forecast technique for the magnitude of the isallohyptic centers under Case I, the general graphic technique outlined in the previous chapter was followed. Parameters were paired on the belief that a relationship to the tendency magnitude may exist. Isolines of R_1 (magnitude of the isallohyptic center for the following 24 hrs.) were drawn on graphs with the various parameter pairs as coordinates. The majority of the isoline patterns, including mean patterns, showed no regularity or trend as tabulated in Table 3.

For the mean patterns the procedure was to divide the graph into equal square areas of convenient abscissa and ordinate intervals. Adjustment of the mean values over the squares was made utilizing a method of Brooks and Carruthers [8]. Except for the isoline patterns that showed some regularity prior to averaging, the mean value technique did not assist sufficiently to smooth out the very irregular distribution of the isolines.

From the patterns that showed a "fair" regularity of R_1 isolines, graphic combinations of X_5 (the difference of the 200 ft. contour spacing at the inflection point and the trough line with corrections for latitude) with $1/X_7$ (curvature at the trough line), as shown in Figure 3, and X_1 (direction of the inflection point from the mid-point of the trough line) with X_6 (temperature difference at the inflection point and the trough line), as illustrated in Figure 4, were integrated

TABLE 3

REGULARITY OF ISOLINE PATTERN OF R_1
WITH SEVERAL PARAMETER PAIRS (CASE I)

Parameter	Parameter	Isolines	Regularity of Isoline Pattern
X_1	X_8	R_1	None*
X_1	X_4	R_1	None
X_8	X_4	R_1	None
X_1	X_6	R_1	Fair
X_5	X_7	R_1	Fair
X_5'	$1/X_7$	R_1	Fair
X_5'	X_1	R_1	None
X_5'	X_7	R_1	None
X_5''	X_4	R_1	None
X_5''	X_7	R_1	None
X_5''	X_8	R_1	None
X_5''	R_3	R_1	None
	Mean Patterns		
X_5'	X_1	R_1	None
X_5'	X_7	R_1	None
X_8	X_1	R_1	None
X_5'	$1/X_7$	R_1	Fair
X_5''	X_7	R_1	None

* Indicates no definite centers of maximum and minimum values were established by the isolines and the pattern was very irregular with no established trend.

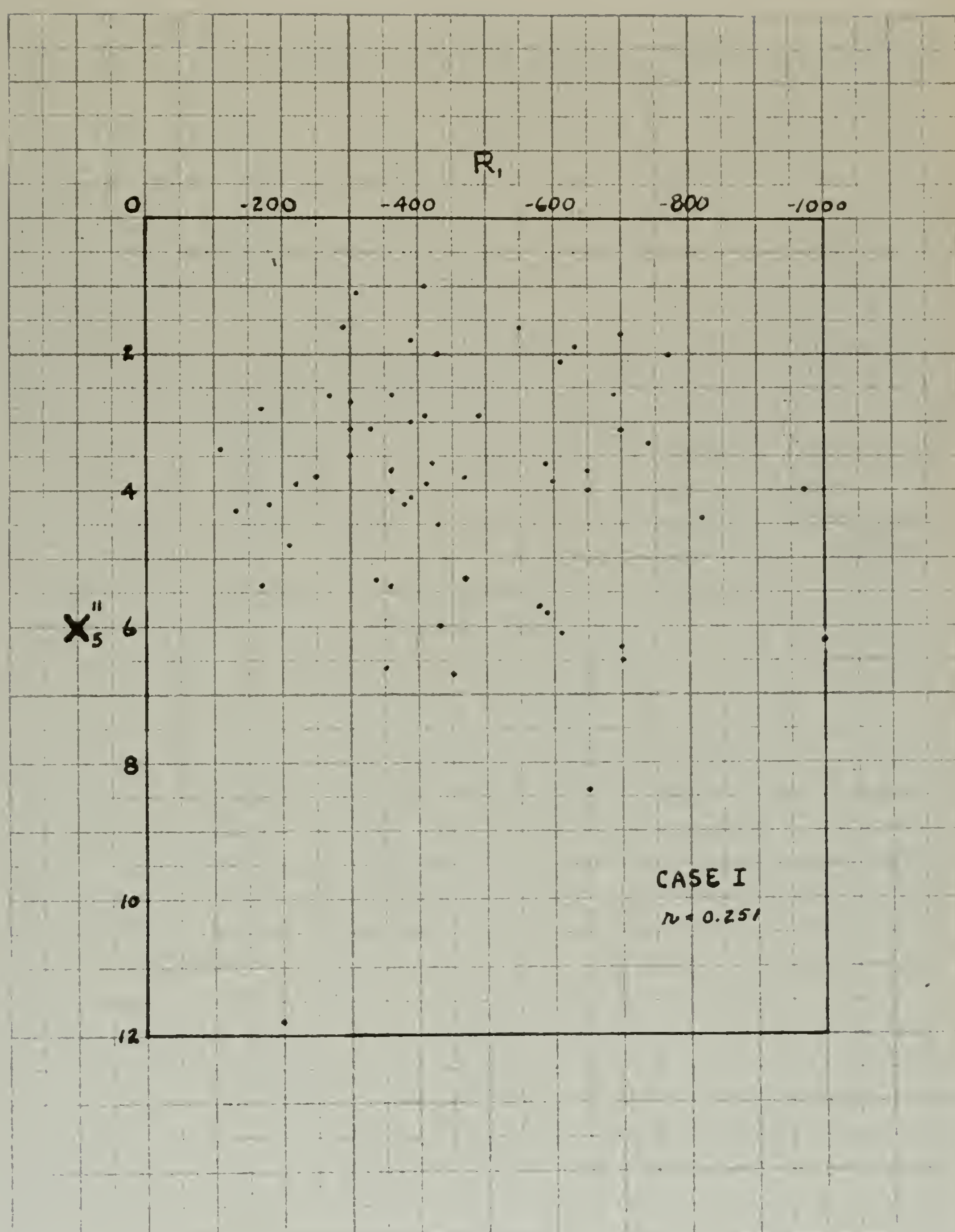


FIGURE 2

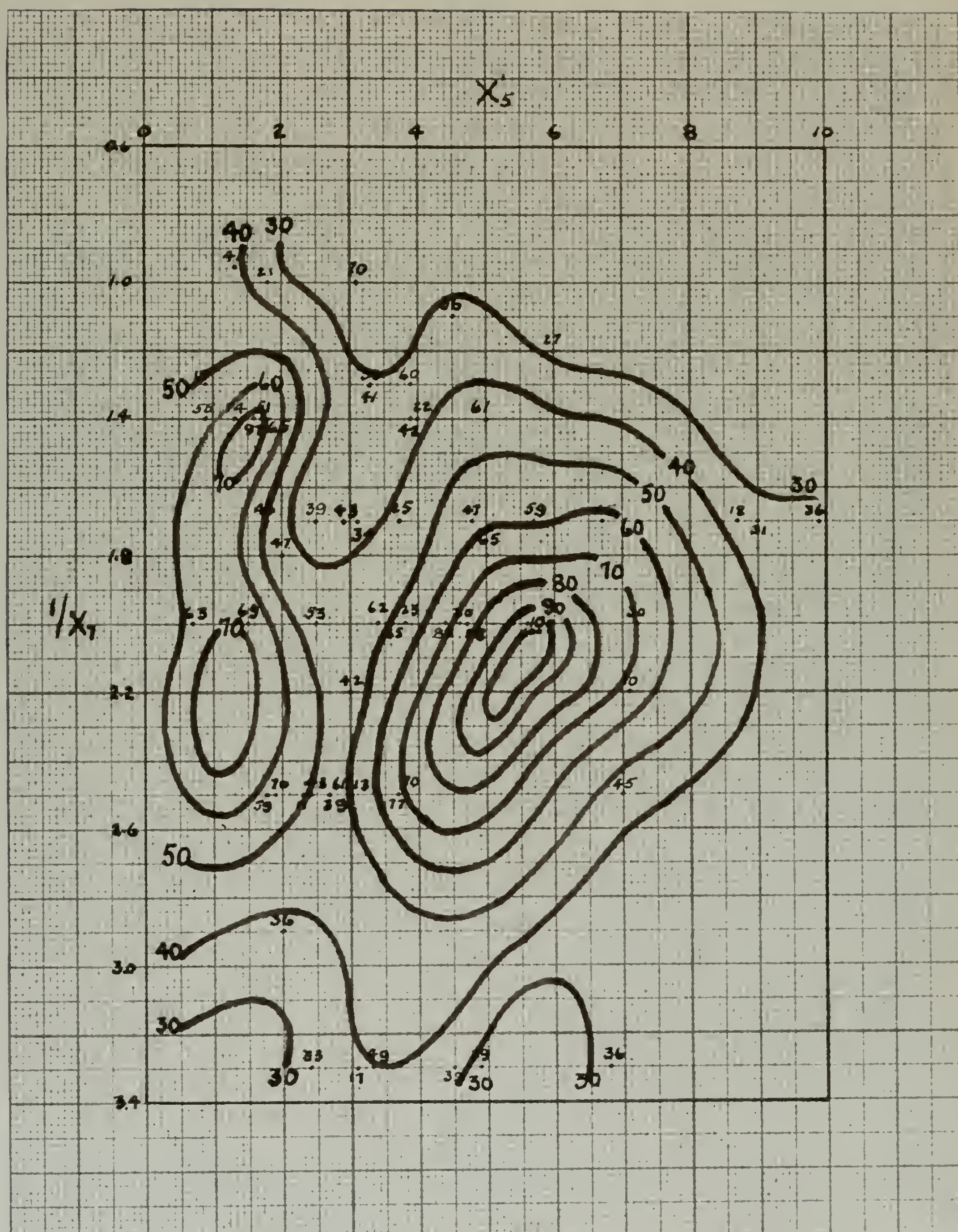
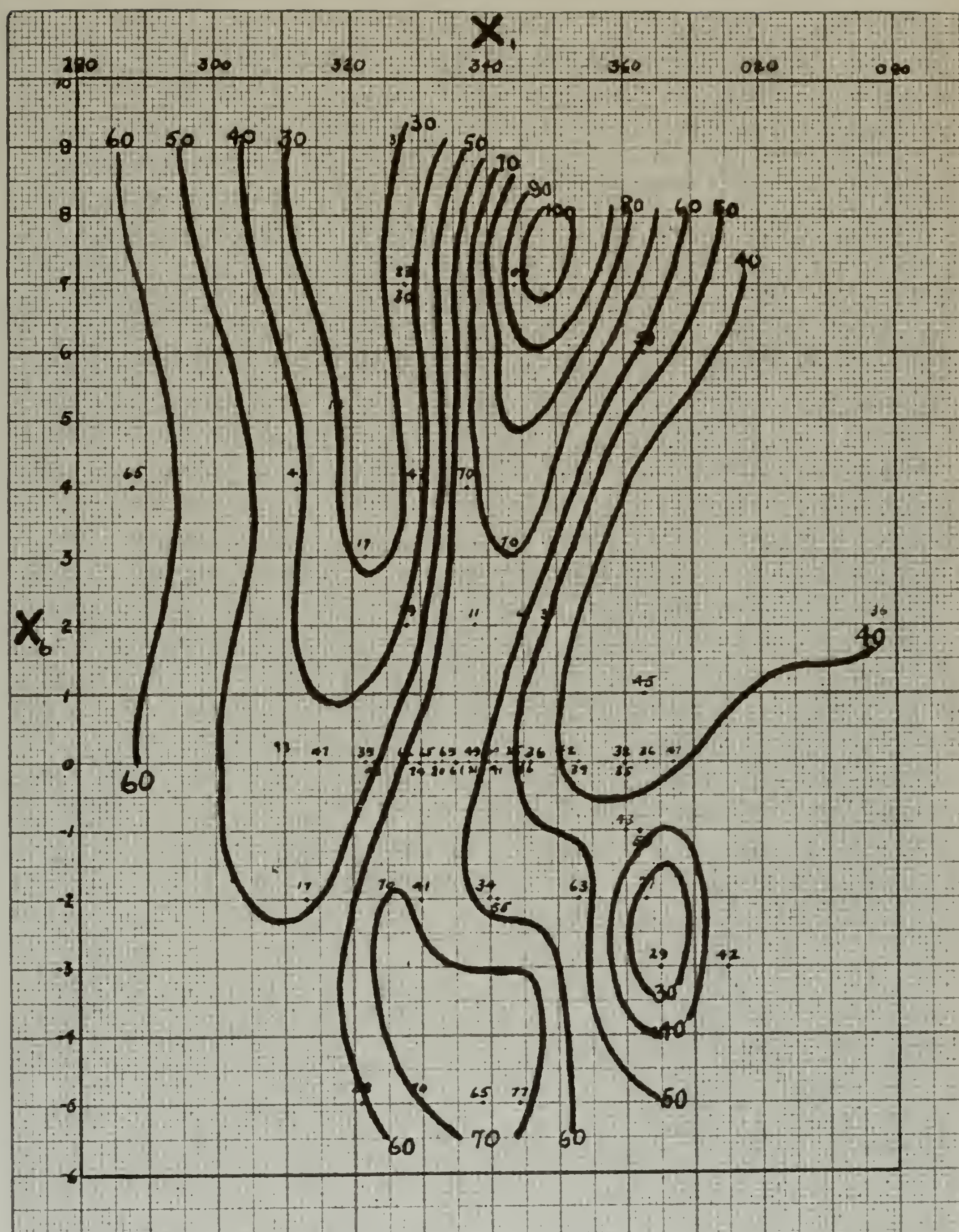


FIGURE 3



X_1
X_6
280
300
320
340
360
020
040
60
50
40
30
30
50
70
90
100
80
60
50
40
40
60
60
70
60
60
30
40

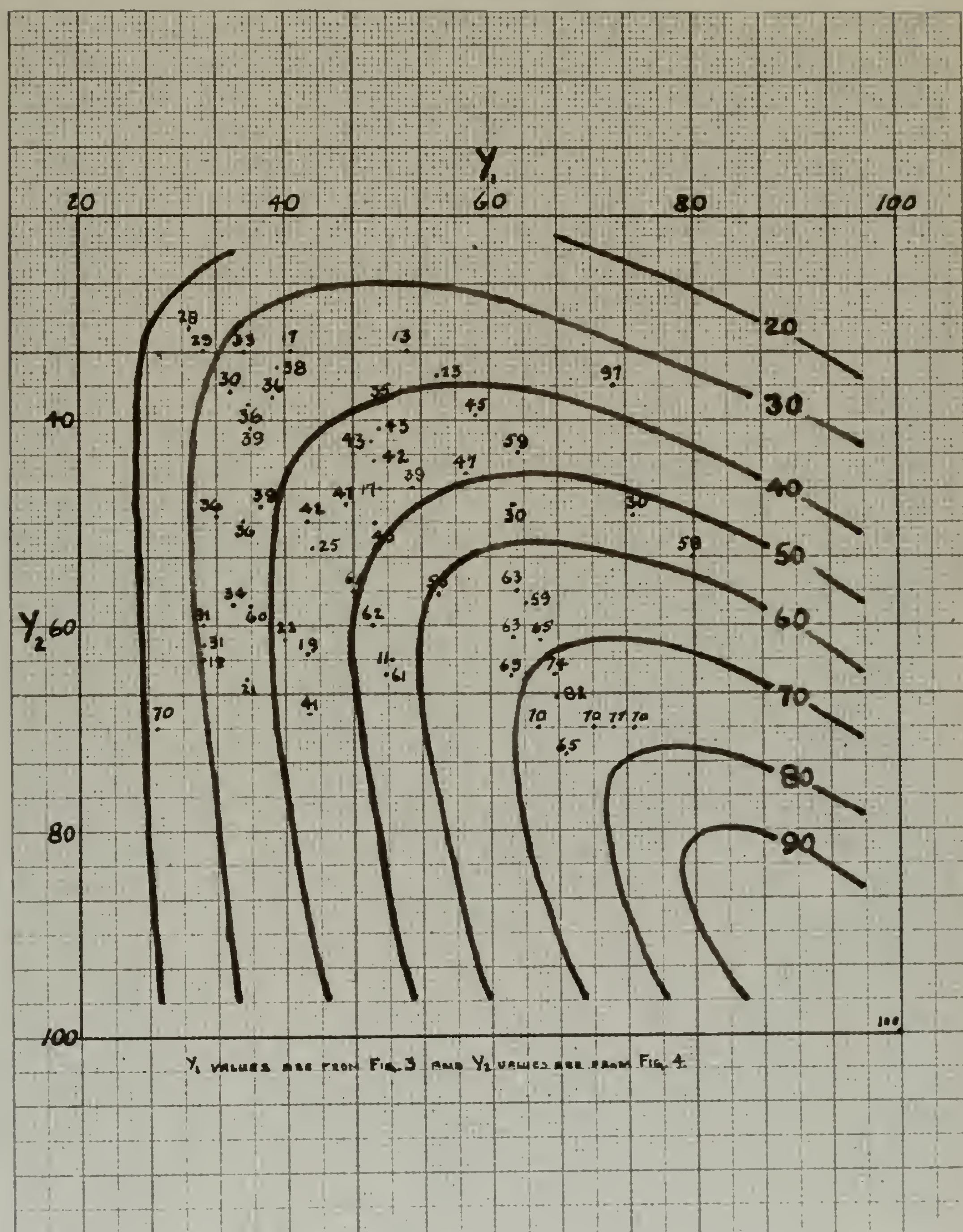
FIGURE 4

into a third graph. Using the parameter Y_1 for the values obtained from Figure 3 and the parameter Y_2 for those obtained from Figure 4, the third graph was constructed, as shown in Figure 5. This final graph developed a smooth pattern with only a few isolated points at extreme deviations from the isoline intervals.

The original data were tested with this graphic technique and the comparison of the derived to the actual values yielded a significant correlation coefficient of 0.670. However, the technique was not successful when an independent sample of 18 cases for the period July to December 1950 was tested. The resulting correlation of these derived values with their actual reported tendencies was only 0.260, which is not significant at the 5% level.

The explanation for this very poor result is lacking. In the construction of the graphs in Figures 3 and 4, data within a certain range of direction of the tendency centers were added to other ranges until the 60 cases had been included. At each step the positions of the maximum and minimum centers on the graphs remained stable and, although the isoline patterns of the graphs are readily seen to be somewhat irregular, there was a belief that consistency had been established.

On examining the results from the 18 independent cases, some interesting facts may be brought out. Table 4 shows the comparison of the observed values with the derived values and, despite the poor correlation coefficient, 16.8% verified for an interval of 100 ft. or less, 55.6% for 200 ft. or less, 72.3% for 300 ft. or less, 88.8% for 400 ft. or less and 100% for 500 ft. or less. Except for



Y_1
20
40
60
80
100
Y_2
40
60
80
100
20
30
40
50
60
70
80
90
Y_1 values are from Fig. 3 and Y_2 values are from Fig. 4.

FIGURE 5

TABLE 4

COMPARISON OF OBSERVED VALUES OF THE 18
INDEPENDENT SAMPLES WITH DERIVED VALUES
USING FORECAST TECHNIQUE

Sample Number	Actual Value	Derived Value	Difference
1.	-710 ft.	-270 ft.	440 ft.
2.	-560	-360	200
3.	-840	-730	110
4.	-670	-510	160
5.	-510	-710	200
6.	-970	-570	400
7.	-250	-450	200
8.	-830	-510	320
9.	-540	-410	130
10.	-660	-370	290
11.	-650	-420	230
12.	-300	-460	160
13.	-550	-330	220
14.	-420	-750	330
15.	-450	-370	80
16.	-500	-410	90
17.	-770	-340	430
18.	-320	-340	20

the smallest interval of 100 ft. or less, these percentages were a greater verification than those obtained from a forecast of persistence of the magnitude centers. A comparison of these percentages is given in Table 5.

A particularly interesting result was shown in sample #4 of Table 4 where the previous values of the tendency center had been zero for 48 hours. A forecast based on persistence of the tendency center, or also one based on persistence of the change of isallohyptic center in 24 hours, would yield a zero value for the center in the following 24 hours. The actual value that was observed is shown as -670 ft. The forecast resulting from the graphic technique was -510 ft., a deviation of only 160 ft. from the observed value compared to a deviation of 670 ft. based on either of the persistence forecasts.

Since the multiple graphic technique was unsuccessful in obtaining a useful forecast aid, persistence forecasts were investigated for their significance when Case I contour patterns were present. When a forecast of persistence of magnitude for 24 hours was made, no significant relationship was established with computed correlations of 0.208 for the 60 original samples and 0.080 for the 18 independent samples. However, a significant relationship was obtained when a forecast of the change of the isallohyptic center in the following 24 hours is based on the change of the center in the past 24 hours. The result was a negative correlation of -0.589, as shown in Figure 6, signifying that when the magnitude of the center increased (decreased) during the past 24 hours, there is a tendency for the center to decrease (increase) in the following 24 hours. Table 5 shows percentages

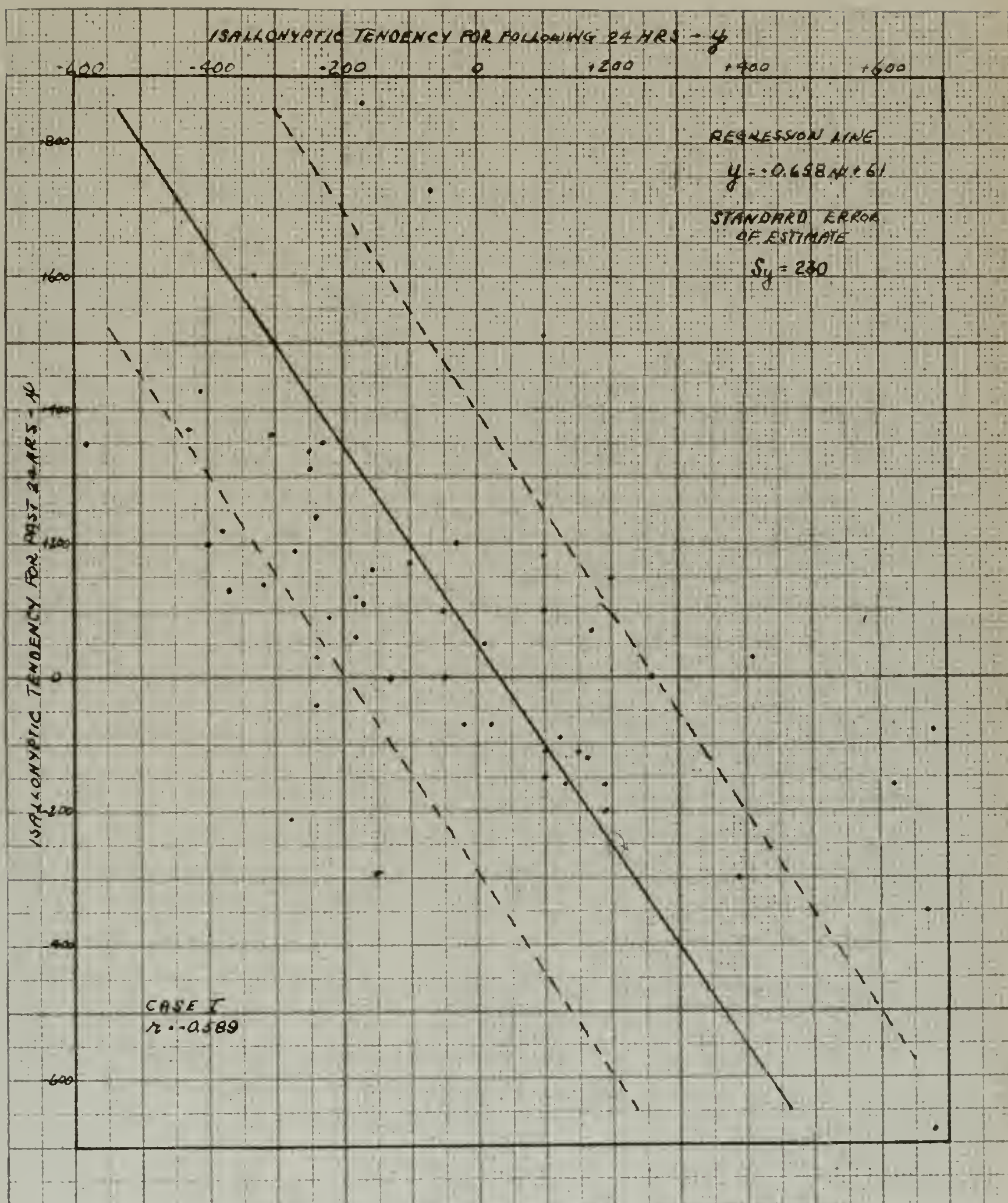

ISALLONYPTIC TENDENCY FOR FOLLOWING 24 HRS - y
-600 -400 -200 0 +200 +400 +600
REGRESSION LINE
y = -0.658 x + 61
STANDARD ERROR OF ESTIMATE
S_y = 230
ISALLONYPTIC TENDENCY FOR PAST 24 HRS - x
CASE I
r = -0.589

FIGURE 6

of verification for the persistence forecasts as compared to the verification for the original and independent data using the forecast graph technique. From the results it is seen that the best relationship established under the present investigation for magnitude forecast associated with Case I was the tendency of the isallohyptic fall center to deepen (fill) in the following 24 hours when the center filled (deepened) in the past 24 hours.

TABLE 5

VERIFICATION PERCENTAGES FOR 100 FT. INTERVALS OF TESTED RELATIONSHIPS IN THE FORECAST OF ISALLOHYPTIC CENTER MAGNITUDE (CASE I)

Contour Interval	Persistence of Magnitude	Forecast Graph Orig. Data	Forecast Graph Indep. Data	Forecast Based on Past 24 Hour Center Change *
±100 ft.	24.1%	74.5%	16.8%	49.2%
±200	51.7	88.1	55.6	69.2
±300	72.4	94.9	72.3	83.7
±400	84.5	94.9	88.8	87.3
±500	89.6	96.6	100.0	91.0
±600	93.1	96.6	100.0	92.8
±700	97.3	100.0	100.0	98.3
±800	100.0	100.0	100.0	100.0

* From the value of the isallohyptic change in the past 24 hours an equal amount of opposite sign was forecast for the next 24 hours.

It was then decided to determine if the above results for Case I applied to all isallohyptic centers. This possibility was investigated for a wintertime situation with the same area of the previous investigations and included 335 fall centers representing the total number occurring during the months of December 1949 to December 1950.

The correlation of the past 24 hours center change with the following 24 hours remained negative, as in Case I, but its value of -0.100 is not significant and would occur frequently in random samples of the same size from a population in which the two variables were uncorrelated. From this result it is apparent that the relationship established for Case I does not hold for all isallohyptic fall centers, at least in a wintertime situation. This will be useful as an indication of the future change in the magnitude of the center when the contour pattern of Case I has been observed on the current map.

For the same 335 fall centers a correlation of 0.325 for persistence of magnitude was significant above the 1% level, which was not true for the samples of Case I.

2. Case II.

The synoptic situation defined under Case II is that weak winds are approaching cyclonically curved contours of stronger gradient, which results in isallohyptic rises. As in Case I the 24 hour isallohyptic centers from the height change charts were used as a measure of determining the effects on the contour field.

There was no exception to the association of the isallohyptic center rises from the 44 samples selected for Case II, which with 95% confidence contain 90% of the population between the sample extremes.

The area of contour rises and the non-existence of contour falls within the area were even more pronounced than the isallohyptic fall regions of Case I.

The correlation of R_1 (magnitude of the isallohyptic center for the following 24 hours) with X_5'' (a measure of the geostrophic wind difference at the inflection point and the trough line) did not show much improvement from the previous case. Its value of 0.351 is associated with the scatter diagram of Figure 7. However, this correlation is above the significance level of 5% and indicates a real relation between the two variables, which was not true for a similar relationship in Case I.

The major portion of the investigation was devoted to Case I, and only a few parameters were combined to formulate a forecasting technique for Case II. As mentioned previously it was felt that the relationships established for Case I would hold to some degree in Case II; but the combinations of variables, which had a "fair" success, did not show any regularity or trend of pattern in Case II as tabulated in Table 6.

No further investigation was made using the multiple graphic technique for Case II because of time limitations. However, the results from the persistence forecasts for Case II were quite different from those of Case I. The highest correlation was not a relationship based on the past 24 hour change of the isallohyptic center as in Case I. For Case II this relationship gave a computed value of -0.382, which shows some real relation at the 5% level for the 44 samples, but is not as highly significant as that of Case I.

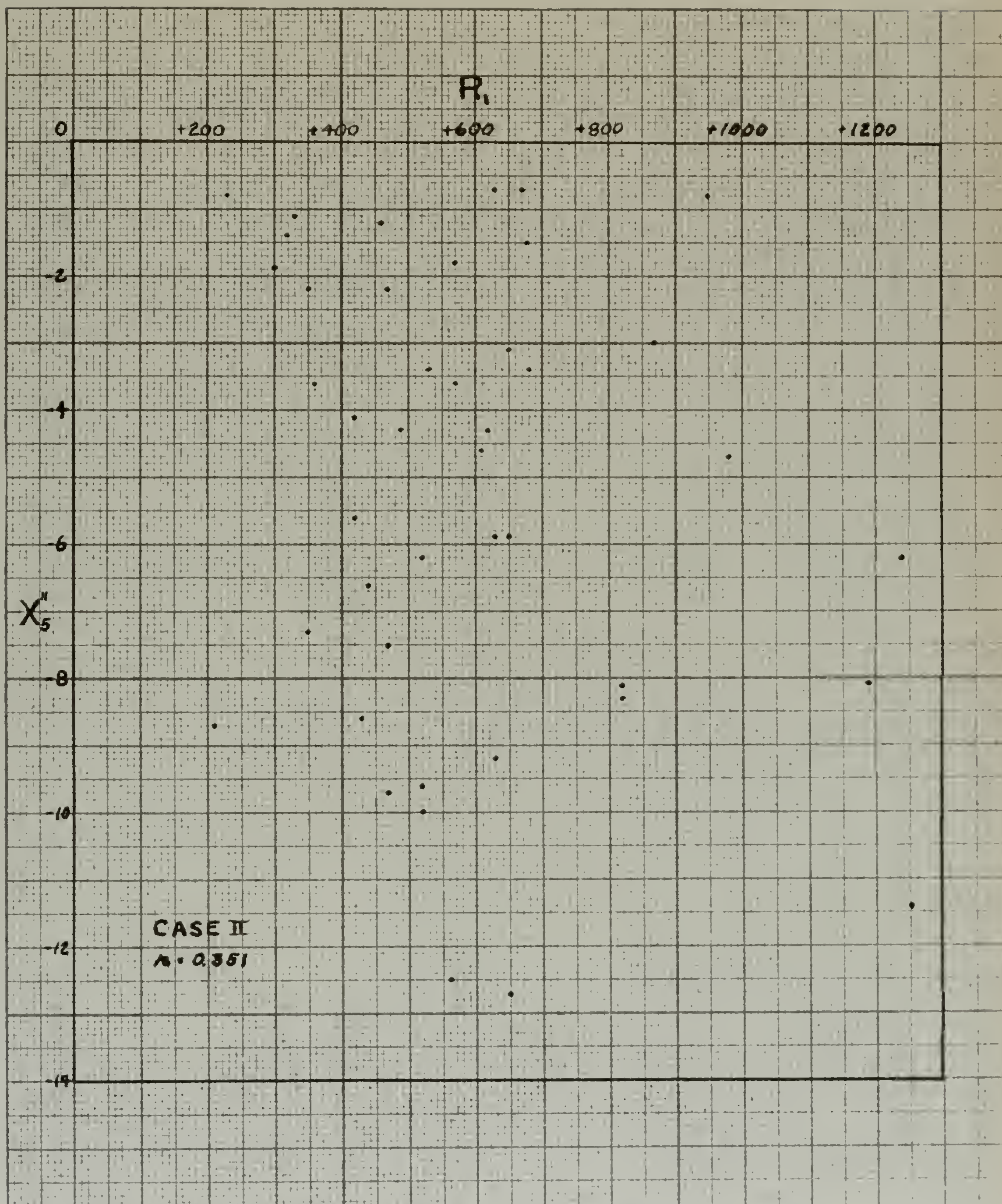


FIGURE 7

TABLE 6

REGULARITY OF ISOLINE PATTERN OF R_1
WITH SEVERAL PARAMETER PAIRS (CASE II)

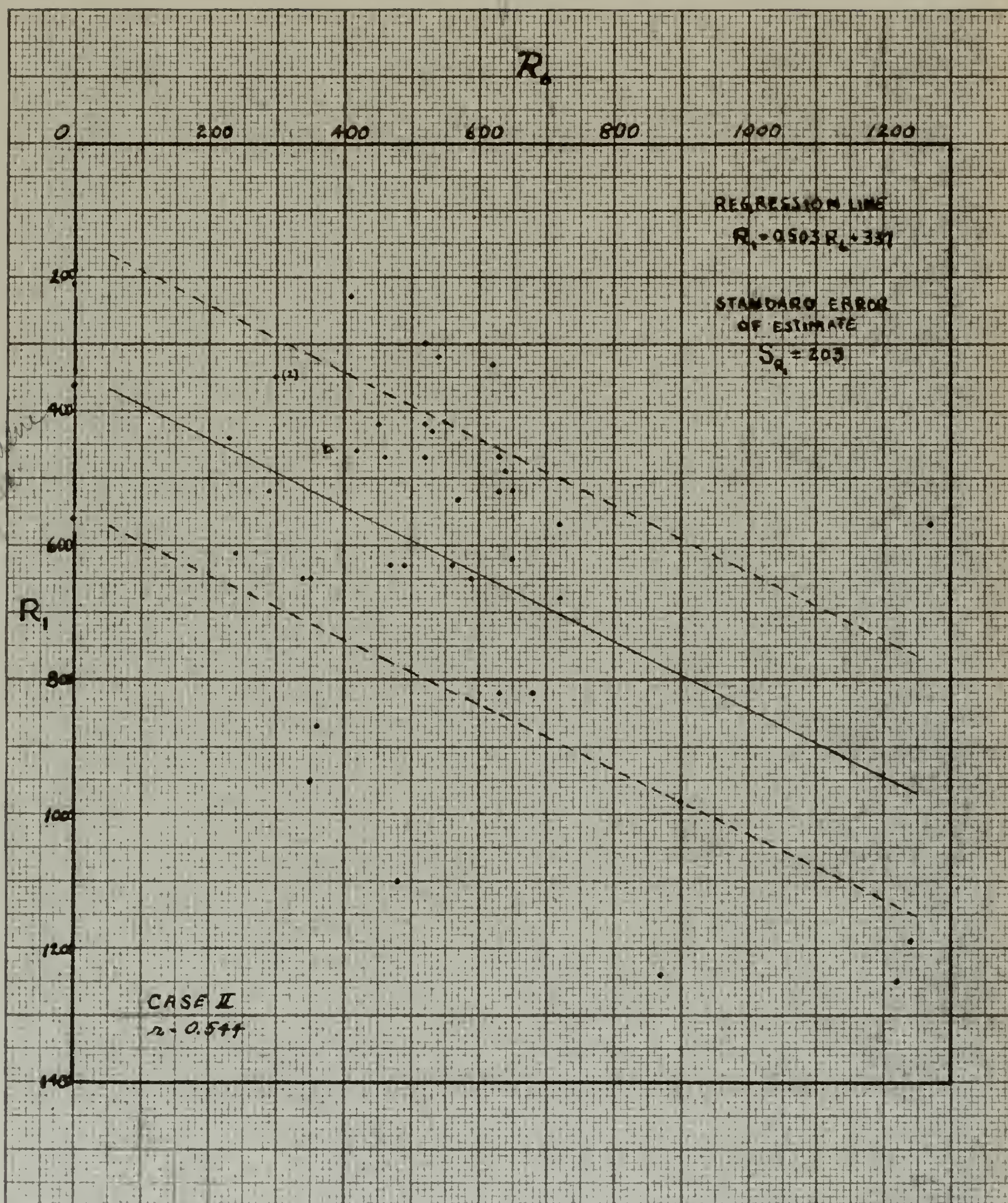
Parameter	Parameter	Isolines	Regularity of Isoline Pattern
X_5'	$1/X_7$	R_1	None
X_5''	X_1	R_1	None
X_5''	$1/X_7$	R_1	None
X_5''	X_7	R_1	None
X_1	X_6	R_1	None

The best relationship was persistence of magnitude for the 24 hour period with a correlation of 0.544, as compared to the small insignificant correlations derived for Case I. The scatter diagram showing this correlation is illustrated in Figure 8.

3. Case III.

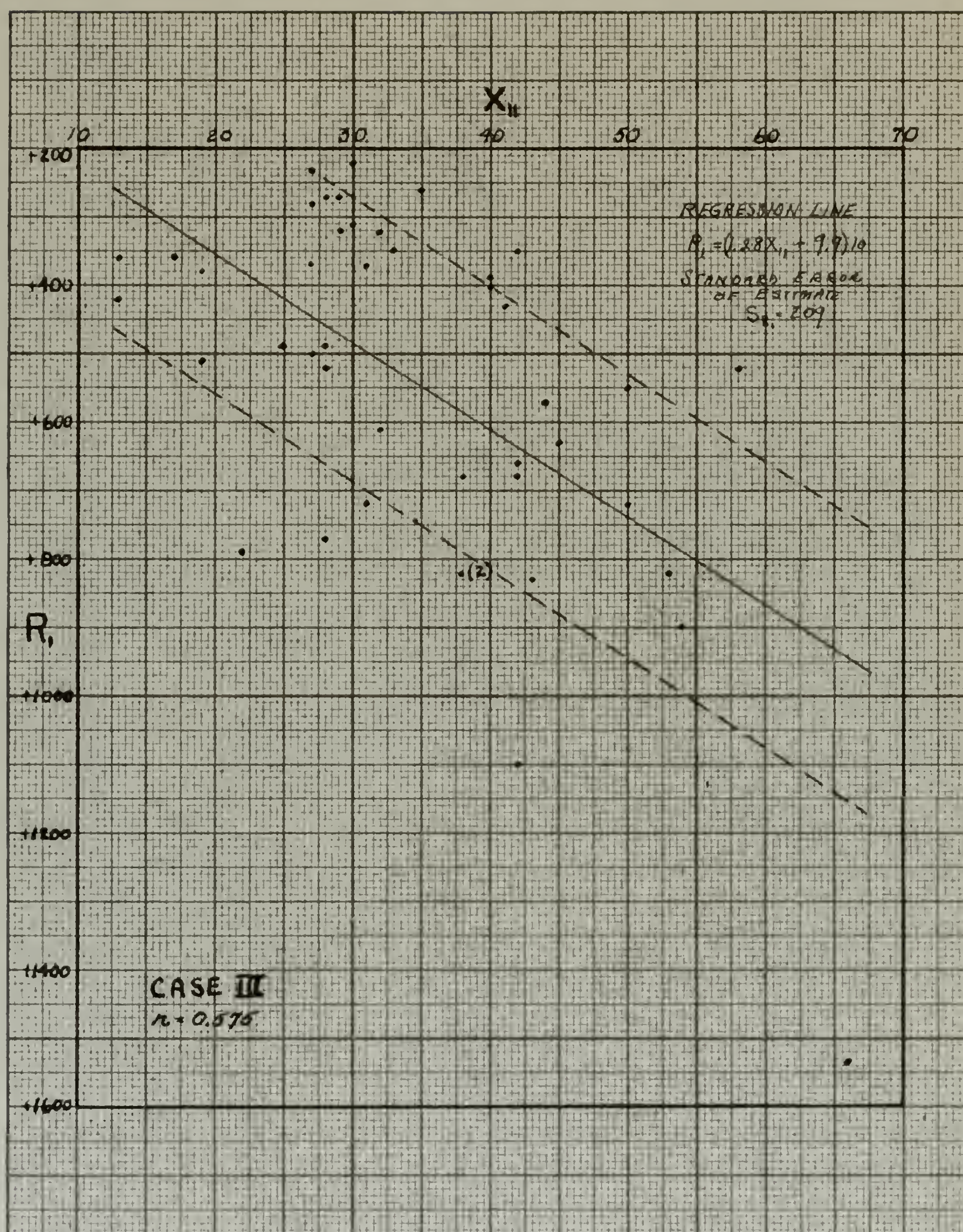
In Case III strong winds approach anticyclonically curved contours of a weaker gradient. Without exception the 24 hr. isallohyptic rise centers were associated with the 45 samples of Case II, which with 95% confidence contain 90% of the population between the sample extremes. The predominance of rise areas was as pronounced as Case II.

Instead of the parameter X_5'', geostrophic wind was measured directly. The correlation of X_{11} (the difference of geostrophic wind at the inflection point and at the trough line) with R_1 (the magnitude of the isallohyptic center for the following 24 hours) was 0.575, as shown in Figure 9. This correlation was very significant



R
0
200
400
600
800
1000
1200
REGRESSION LINE
R1 = 0.503 RL + 337
STANDARD ERROR
OF ESTIMATE
S = 203
R1
CASE II
r = 0.544

FIGURE 8



X11
10
20
30
40
50
60
70
+200
+400
+600
+800
+1000
+1200
+1400
+1600
R1
REGRESSION LINE
R1 = (1.28X11 + 9.9)10
STANDARD ERROR
OF ESTIMATE
S1 = 209
(2)
CASE III
r = 0.575

FIGURE 9

in comparison to the previous cases.

An almost identical correlation as that of Case II was obtained for the persistence of magnitude of the isallohyptic rise centers in Case III. The computed value was 0.548, as shown in the scatter diagram of Figure 10.

For persistence of the isallohyptic center change a correlation of -0.186 was obtained; and although it is negative, as in the previous cases, for the 45 samples the value is not significant, in contrast to the relationship established in Cases I and II.

Time prevented any graphic technique development and from the limited investigation the best relationship to the magnitude of the isallohyptic rise centers in the following 24 hours is that of the geostrophic wind difference at the inflection point and at the trough line from the current map.

A test was made for wintertime rise centers similar to the investigation of fall centers. A total of 406 samples was obtained for the period, December 1949 to February 1950. Significant correlations above the 5% level were computed for both persistence of magnitude (0.293) and persistence of magnitude change (-0.288), showing real, although small, relationships. A comparison of these values is shown in the summary at the end of the chapter.

4. Summary of All Cases.

As a conclusion to the investigation of magnitude of the isallohyptic centers, statistical computations were made for the means and standard deviations of Cases I, II and III and the wintertime isallohyptic fall centers. These values are shown in Table 7 which also includes the correlations of all Cases for comparison.

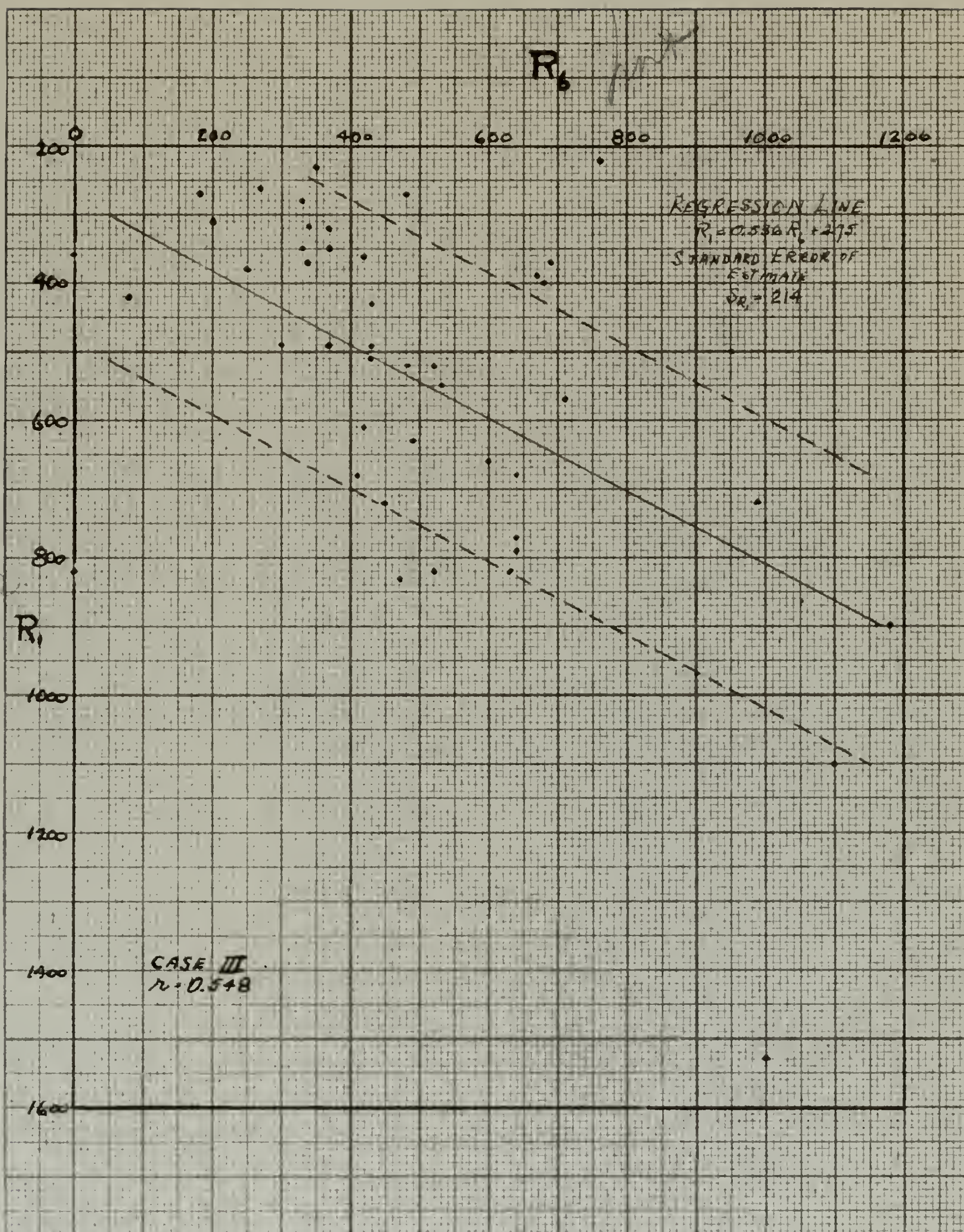

R_6
0
200
400
600
800
1000
1200
REGRESSION LINE
$R_1 = 0.530 R_6 + 275$
STANDARD ERROR OF ESTIMATE
$S_{R_1} = 214$
R_1
200
400
600
800
1000
1200
1400
1600
CASE III
$r = 0.548$

FIGURE 10

TABLE 7

SUMMARY AND STATISTICAL DATA FOR ISALLOHYPTIC CENTER MAGNITUDE INVESTIGATION

Case	Number of Observations	Mean of Associated Center	Standard Deviation
I	60	-496 ft	206 ft
II	44	+605	254
III	45	+542	259
Wintertime Fall Centers	335	-577	269
Wintertime Rise Centers	406	+550	231

Correlation Summary

Case	Persistence of Magnitude	Persistence of Magnitude Change	Correlation of X_5'' or X_{11} with Center Magnitude
I	0.208	-0.589	0.251
II	0.544	-0.382	0.351
III	0.548	-0.186	0.575
Wintertime Fall Centers	0.325	-0.100	---
Wintertime Rise Centers	0.293	-0.288	---

CHAPTER IV

DIRECTION OF THE ISALLOHYPTIC CENTERS

1. Case I.

The fall areas associated with the stronger wind approaching cyclonically curved contours of weaker winds are stated in Case I as occurring to the left of the air parcel trajectory. Letting the co-direction of the parameter X_1 (direction from the trough line to the inflection point) represent a rough measure of the air parcel trajectory, the deviation of R_2 (24 hour isallohyptic center direction from the trough line of the current map) from the co-direction of X_1 was to the left for 83.4% of the 60 samples of Case I as illustrated in Figure 11.

The forecast of the direction of the isallohyptic centers has been the object of many investigations with very few promising results. Wolff [9] suggested extrapolation along the long wave pattern as the best method for the movement of 24 hr. isallohyptic centers. No quantitative results were included and the technique was not considered. A higher level was studied for possible steering of the 500 mb. centers in a later investigation.

Persistence of direction of the isallohyptic centers in Case I resulted in a correlation of 0.249, which is not significant for the 60 samples and indicates the non-existence of any relationship.

In the development of a forecast technique for direction of the isallohyptic centers, a similar pattern in the combination of parameters

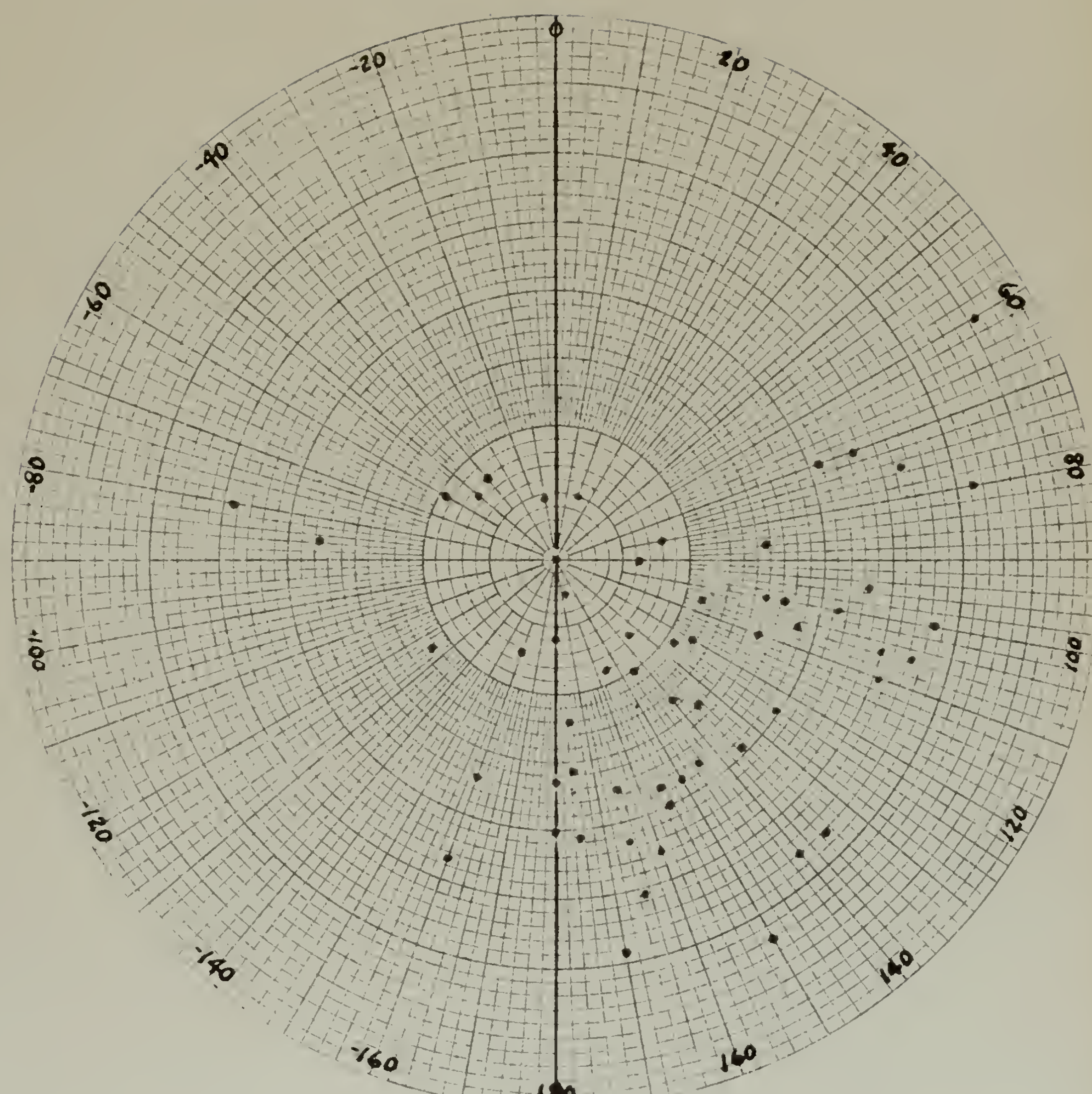


FIGURE 11

for the magnitude investigation was carried out. Scatter diagrams of a few parameter pairs were constructed for the establishment of a direct relationship without success as shown by the correlations tabulated in Table 8.

TABLE 8

CORRELATION OF SEVERAL PARAMETER PAIRS FOR CASE I

Parameter	Parameter	Correlation
$X_1 - R_2$	X_5	0.139
X''_5	$X_1 - R_2$	None *
X''_5	$R_7 - R_3$	None
X''_5	X_1	None
X_2	R_3	None
X_2	$R_7 - R_3$	None

The isoline patterns of R_2 (direction of the 24 hr. isallohyptic center from the trough line) with various combinations of parameter pairs were very irregular, excepting one combination, as shown in Table 9. The coordinates for this combination were X_9 (the measure of geostrophic wind at the inflection point) and X_4 (temperature difference over a 10 degree latitude distance centered at the inflection point and perpendicular to the wind flow at the inflection point), as graphed in Plate III with isolines of R_2. For both the

* "None" in this table indicates the scatter diagram showed that no significant correlation could be established.

original data of 60 samples and the independent data of 18 samples a fair degree of success was obtained.

TABLE 9

REGULARITY OF ISOLINE PATTERN OF R_2
WITH SEVERAL PARAMETER PAIRS (CASE I)

Parameter	Parameter	Isolines	Regularity of Isoline Pattern
X_5''	$1/X_7$	R_2	None
X_5''	X_7	R_2	None
X_5''	X_4	R_2	None
X_9	X_4	R_2	Good
X_2	X_4	R_2	None
X_8	X_5''	R_2	None
X_8	X_2	R_2	None
X_8	X_{10}	R_2	None
X_5''	X_{10}	R_2	None
	Mean Patterns		
X_5''	X_7	R_2	None
X_5''	$1/X_7$	R_2	None
X_5''	X_4	R_2	None

Table 10 compares the percentage verification of the forecast graph with a forecast based on persistence and illustrates the improvement obtained from the use of the graph. In regard to the comparison of

the original with the independent data results, a slight decrease in percentage verification occurred up to an interval of 20 deg., which is usually expected for independent tests. However, for larger intervals the independent data showed a considerably higher degree of verification, possibly indicating a greater reliability than that established by the original data.

TABLE 10

VERIFICATION PERCENTAGES FOR 10 DEG. INTERVALS OF FORECAST GRAPH AND PERSISTENCE OF ISALLOHYPTIC CENTER DIRECTION (CASE I)

Direction Angle Interval (Deg)	Persistence of Direction	Forecast Graph Orig. Data	Forecast Graph Indep. Data	Forecast Graph Weighted Average
±10	23.2%	35.3%	33.3%	34.8%
±20	37.5	54.9	50.0	53.8
±30	46.6	60.7	72.2	63.4
±40	53.6	66.6	83.3	70.5
±50	62.5	74.5	88.8	77.8
±60	67.8	84.3	94.4	86.6
±70	75.0	92.1	100.0	93.9
±80	82.2	98.0	100.0	98.5
±90	87.5	98.0	100.0	98.5
±100	100.0	100.0	100.0	100.0

When the isolines of R_2 on the forecast graph were replaced by isolines of R_3 (isallohyptic center direction for the following

24 hours from the current position of the center), there was no regularity of pattern established. Only the graph with isolines of the isallohyptic center direction from the trough line was successful as a forecasting aid.

2. Case II.

Case II states that with weaker winds approaching the stronger gradient of cyclonically curved contours, contour rises occur to the left of the air parcel trajectory. Using the assumption of Case I regarding the trajectories, 86.3% of the 44 samples of Case II occurred to the left, as shown in Figure 12.

The only tested combination of parameters for Case II was X_9 and X_4 with isolines of R_2 for the reason of success achieved under Case I. The pattern was very irregular and could not be applied to Case II.

There was no relationship established for persistence of direction of the isallohyptic rise centers associated with Case II. The computed correlation was 0.200 which is not significant.

The best relationship under the limited investigation was a mean direction of C92 degrees true with a standard deviation of 36.0 degrees. A similar standard deviation of 36.5 degrees from a mean of 352 degrees can be expected when the direction of the isallohyptic center for the following 24 hours is measured from the trough line.

3. Case III.

The statement of Case III is that strong winds approaching a weaker contour gradient of anticyclonic curvature will produce

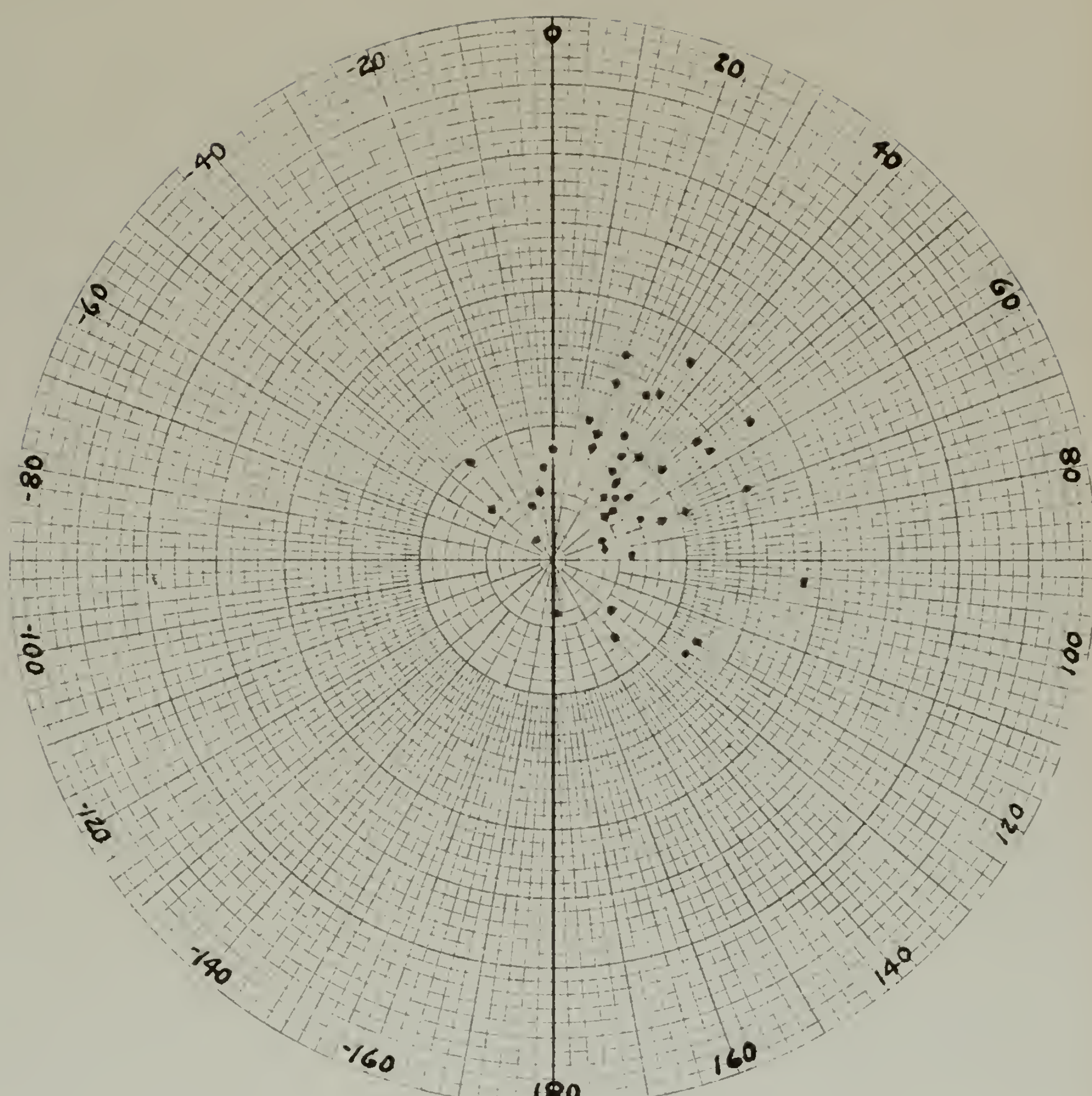


FIGURE 12

rises to the right of the air parcel trajectory. Using the assumption of the two previous cases, isallohyptic rise centers occurred to the right of R_2 (direction from the inflection point to the ridge line) 95.6% of the time for the 45 samples of Case III, as illustrated in Figure 13.

Those parameters which indicated some significance in the other cases were paired and isolines of several dependent variables were tested. No regularity of pattern was obtained, and these results are tabulated in Table 11.

TABLE 11

REGULARITY OF ISOLINE PATTERNS OF SEVERAL VARIABLES WITH SELECTED PARAMETER PAIRS (CASE III)

Parameter	Parameter	Isolines	Regularity of Isoline Pattern
X_9	X_4	$R_2 - X_1$	None
X_9	X_4	R_2	None
X_9	X_4	R_3	None
X_9	X_{11}	R_2	None
X_4	X_1	R_2	None

No significant relationship was shown for persistence of direction, and the computed correlation of -0.227 is not significant for the size.

From the statistical computations of Case III, a standard deviation of 37.8 deg. from the mean of 102 deg. was obtained for the direction of the isallohyptic center, as measured from the ridge line

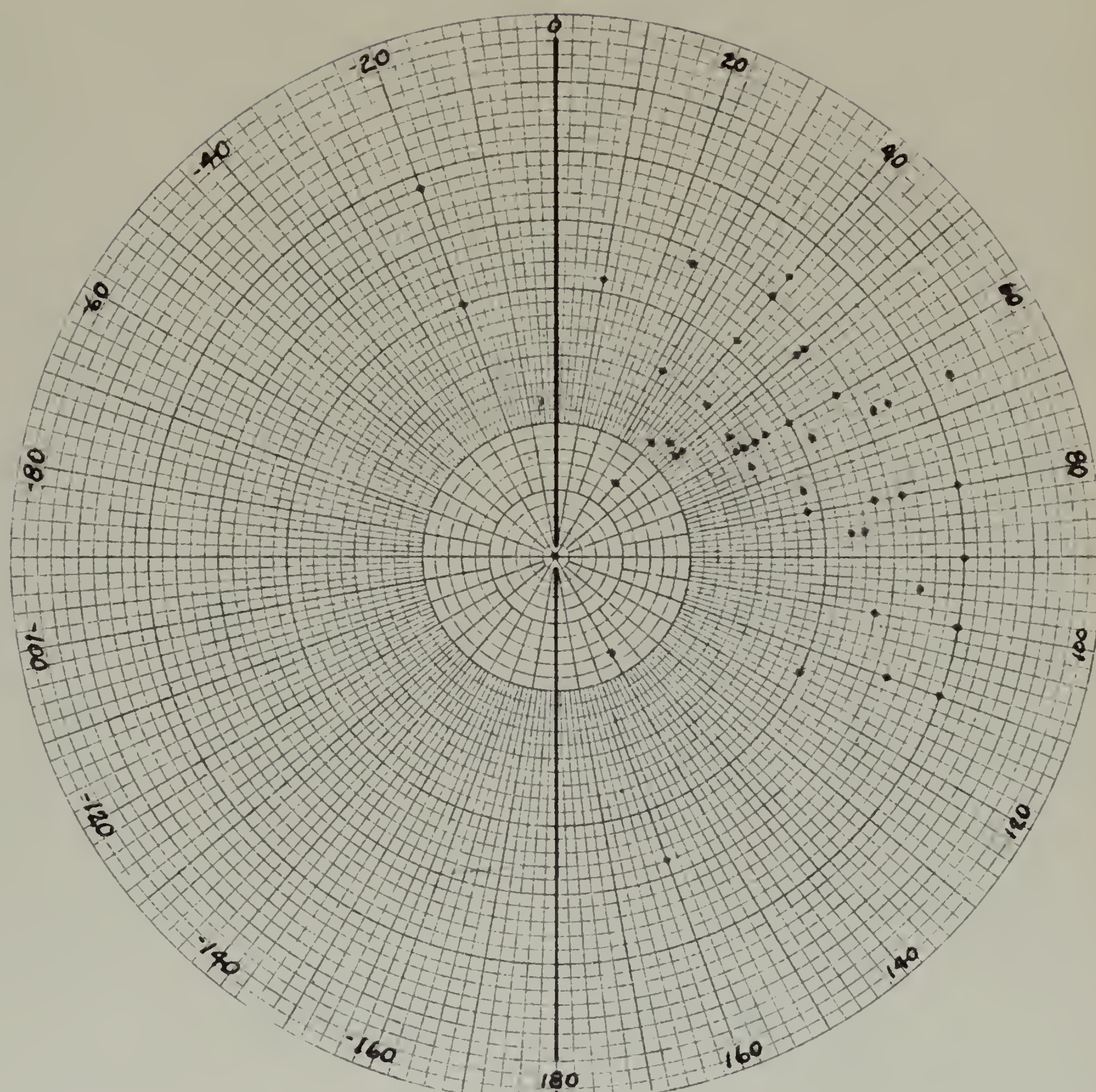


FIGURE 13

of the current map. A standard deviation from the mean direction of the center, as measured from its current position on the height change chart, was slightly higher.

4. Summary of All Cases.

Table 12 gives the statistical computations of the means and standard deviations, the correlations of persistence of direction, and the percentage verifications under the statement of O'Connor's rules.

TABLE 12

SUMMARY AND STATISTICAL DATA FOR ISALLOHYPTIC CENTER DIRECTION INVESTIGATION

Case	Parameter	Mean	Standard Deviation
I	R_2	112 deg.	72.0 deg.
I	R_3	132	49.4
II	R_2	352	36.5
II	R_3	092	36.0
III	R_2	102	37.8
III	R_3	079	44.2

Case	Persistence of Direction	Verification of O'Connor's Rules
I	0.249	83.4%
II	0.200	86.3
III	-0.227	95.6

CHAPTER V

DISPLACEMENT OF THE ISALLOHYPTIC CENTERS

Of the various forecast items for the isallohyptic center, displacement seems to be the least predictable; and previous attempts to find a relationship between displacement and other measurable parameters has generally been unsuccessful. Unfortunately, time limited the desired thorough investigation of this item for each case.

The tilt of the trough or ridge, X_2, was tested for a direct relationship to R_5 (the displacement of the isallohyptic rise center in the following 24 hours) and $R_5 - R_8$ (the change of the displacement in the following 24 hour period). The scatter diagrams of the three cases showed no significant correlation. This parameter was chosen because several authors have made a study of the tilt of troughs and ridges in relation to the future movement at the 500 mb. level. Oliver and Oliver [10] showed that the meridional transfer of angular momentum associated with tilted and curved troughs is of sufficient magnitude and in the right direction to produce observed changes in the circulation pattern. Ernst, Fox and Hutchison [11] concluded that there is a distinct tendency for troughs and ridges to intensify or weaken in relation to a defined negative or positive tilt. Based on the results of these articles, the tilt of the trough (ridge), or a parameter significantly correlated with tilt, was used extensively in the combination of parameter pairs throughout the previous investigations

of magnitude and direction.

The investigation of persistence of displacement did not establish any useful relationships and, although the correlations obtained for Case I and III are significant at the 5% level for the sample sizes, all of the correlations resulted in small coefficients as shown in Table 13.

TABLE 13

CORRELATION SUMMARY
OF PERSISTENCE OF DISPLACEMENT
(ALL CASES)

Case	Correlation
I	0.327
II	0.145
III	0.321

The speed of the trough or ridge during the past 24 hours was tested for a relationship to the displacement of the isallohyptic centers. Correlations were obtained for the speed of the trough or ridge with R_4 (the displacement as measured from the trough or ridge line), R_5 (the displacement of the center from its current position) and $R_5 - R_8$ (the displacement change of the center in the following 24 hours).

It was interesting to find that of the three dependent variables tested, there was only one significant correlation obtained for each case; and in each instance the correlation was with a different variable as shown in Table 14.

TABLE 14

CORRELATION OF SPEED OF TROUGH
(RIDGE) WITH SEVERAL PARAMETERS
(ALL CASES)

Case	Correlation of Trough (Ridge) Speed with R_4	R_5	$R_5 - R_8$
I	0.163	-0.072	-0.485
II	-0.044	0.463	0.172
III	0.329	0.083	0.148

The best relationship established for Case I was that of the trough speed in the past 24 hours with the displacement change of the center in the following 24 hours. The negative correlation of -0.485 shows that in Case I there is a tendency for the displacement to decrease (increase) in the following 24 hours from its previous 24 hour displacement when the speed of the trough was relatively large (small) during the preceding 24 hours.

For Case II, the significant relationship was that of the trough speed with the future 24 hour displacement of the isallohyptic rise center from its current position on the height change chart. The correlation coefficient was 0.463.

The speed of the ridge in Case III gave the best correlation of 0.329 when related to the displacement of the rise center in the following 24 hours as measured from the current position of the ridge line. Although the three correlations were not large, they are

significant for each sample size, and there exists a real relation between the speed of the trough or ridge with the different variables in each case.

A statistical summary of the data for all cases is compiled in Table 15 showing the means and standard deviations of the displacements as measured from the current trough (ridge) line and as measured from the current positions of the centers on the height change chart.

TABLE 15

STATISTICAL DATA FOR ISALLOHYPTIC
CENTER DISPLACEMENT INVESTIGATION

Case	Parameter	Mean	Standard Deviation
I	R_4	8.2	4.0
I	R_5	10.3	4.3
II	R_4	4.7	2.2
II	R_5	11.9	2.5
III	R_4	10.0	3.5
III	R_5	9.9	3.8

CHAPTER VI

SUPPLEMENTARY INVESTIGATION AND CONCLUSIONS

1. 300 Mb. Investigation.

The investigation for the 24 hr. forecast of 500 mb. isallohyptic centers up to this point has purposely considered parameters only at the 500 mb. level. A forecast aid utilizing the 500 mb. data only would be useful in the field where higher level charts are not generally analyzed. However, it was decided to investigate the movement of the 500 mb. isallohyptic centers in relation to the wind field at the 300 mb. level since no reliable method was developed under the previous investigation.

From the rawinsonde data summarized in the daily synoptic series, the direction and speed of the wind at 300 mb. was obtained for the observations of Cases I, II and III. The wind velocity was recorded from the station report nearest the current position of the rise or fall center. If the wind report was outside of the zero isallohypse circumscribing the center or beyond 10 deg. latitude, the observation was not tabulated. Where several reports were approximately equidistant from the center, an average was used. A wind estimate from the contour field directly above the center or a mean wind from the area above the center may be a more suitable parameter; however, 300 mb. charts were not available for the period selected for the study.

For both the fall centers of Case I and the rise centers of Cases II and III, it was apparent from the data that a direct relationship

of the 300 mb. wind direction to the 24 hr. subsequent direction of the 500 mb. tendency center did not exist. This was also true for the 300 mb. wind speed and the 500 mb. center 24 hr. displacement.

A previous investigation by Mansueto [12] showed a relationship of the movement of the 24 hr. isallohyptic centers at 700 mb. to the wind flow at 500 mb. Eastward components of these two variables were compared, and a correlation of 0.586 was obtained for rise centers. However, the correlation was considerably less (0.116) when the relationship was applied to negative centers. It was decided to compare these results with those obtainable from the 500 mb. and 300 mb. levels.

The eastward components of the 300 mb. wind observations and of the 500 mb. isallohyptic center movements were computed for Case I, II and III. The scatter diagrams showed that no relationship existed in contrast to the relatively high correlation obtained by Mansueto for the 700 mb. level. Hence, on the basis of the limited technique, the investigation showed that the wind field at the 300 mb. level could not be used as an indication of the 24 hr. movement of the 500 mb. rise or fall centers.

2. Conclusions.

It was conclusively shown that the contour pattern of Case I, appearing within the jet stream on the current 500 mb. chart, is associated with subsequent 24 hr. isallohyptic fall centers and similarly for rise centers of Cases II and III.

With the exception of the direction forecast graph for Case I, the multiple graphic technique was unsuccessful. The combinations of

parameters failed in establishing any high correlations, probably for the lack of close dynamic relationships. The integrated effects of the atmosphere above apparently are not reflected sufficiently by the 500 mb. contour patterns to enable their use as an indication of future height changes.

The varied persistence correlations obtained for the different cases suggest that some sort of a contour pattern classification for the 500 mb. level may give a better understanding of the complex systems and their future movements. A forecast would then be based on established rules for each of the identifiable types. A first step to the typing of the 500 mb. level may lie in the patterns defined under the three cases of the present investigation. The relationships obtained for forecasting the future movements of the isallohyptic centers were not highly correlated, but the best results of each case singled out a different variable to observe. A summary of the best relationships is given in Table 16.

Blocking situations also should be considered in the classification of types. In this investigation, a change in the movement of the isallohyptic centers was very noticeable when a blocking situation was present. The persistence correlations would probably be higher with the elimination of the blocking conditions, and these situations could then be studied for relationships to the movement of the isallohyptic centers.

A detailed study of the 500 mb. level is presently being conducted by Project AROWA [13]. The 500 mb. Height Change Charts, which were constantly used in the present investigation, are a product of this

research and were greatly appreciated in eliminating time consuming differential analyses. Five-day tracks of height change centers obtained by Project AROWA showed that the regularity of the daily movement of the centers varied with different patterns appearing at the 500 mb. level. Blocking patterns are also the subject of considerable study in this AROWA project and are defined by a classification index. It is possible, then, that other observable patterns may be classified along with the blocks; and forecast techniques may be evolved for each type of pattern.

TABLE 16

SUMMARY OF THE BEST RELATIONSHIPS OBTAINED FROM THE INVESTIGATIONS OF EACH CASE

Case	Magnitude of Center	Direction of Center	Displacement of Center
I	Persistence of Magnitude Change (Neg.)	Forecast Graph (Plate III)	Speed of trough with displacement change (Neg.)
II	Persistence of Magnitude	Mean West-East Direction	Speed of trough with actual displacement
III	Persistence of Magnitude	Mean Direction measured from ridge line	Speed of ridge with displacement measured from ridge line

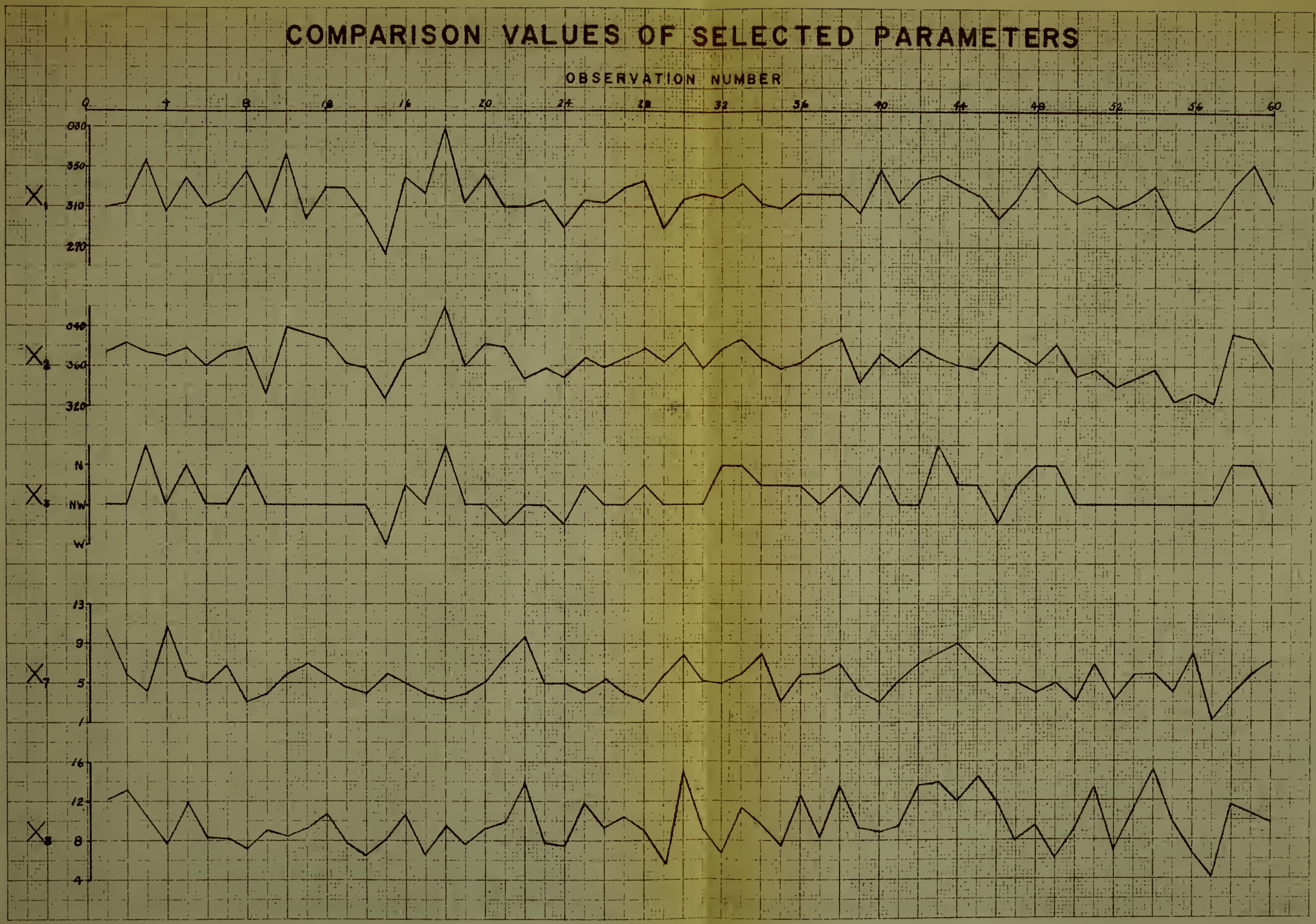
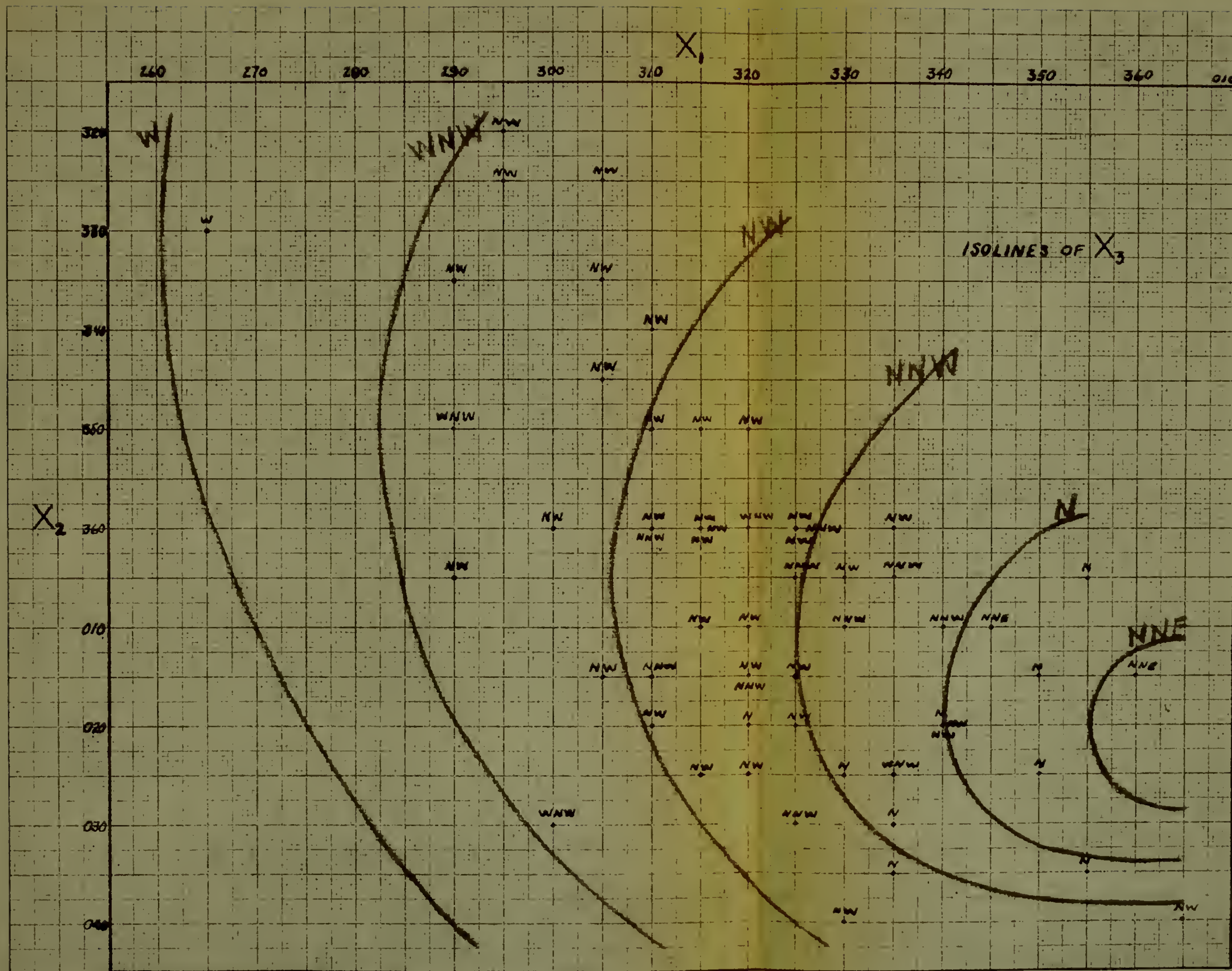
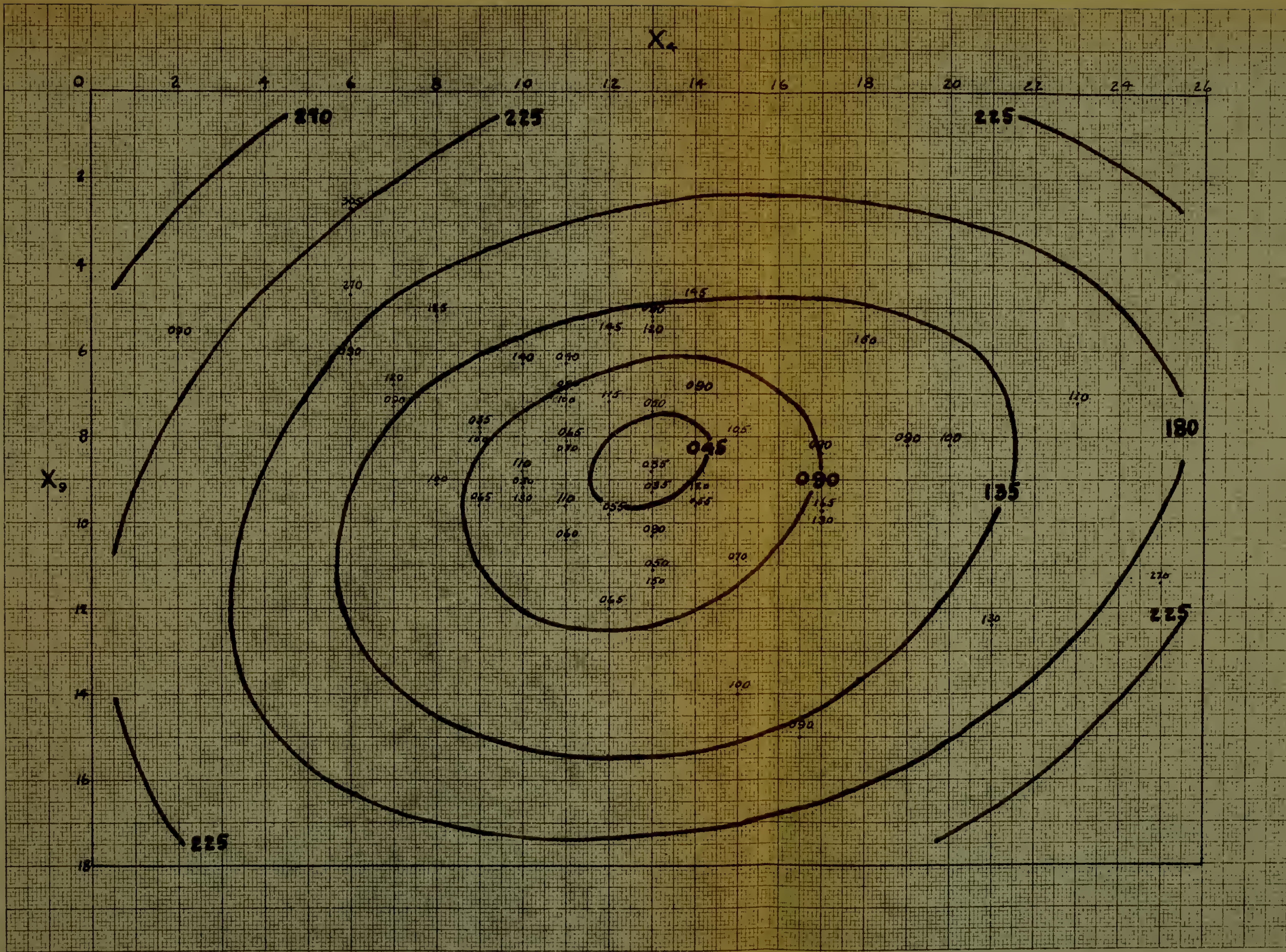

COMPARISON VALUES OF SELECTED PARAMETERS
OBSERVATION NUMBER
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
030
350
310
270
X_1
040
360
320
X_2
N
NW
W
X_3
13
9
5
1
X_7
16
12
8
4
X_8

PLATE I


X1
260
270
280
290
300
310
320
330
340
350
360
010
X2
ISOLINES OF X3
W
WNW
NW
NNW
N
NNE
PLATE II



X₄
X₉
0
2
4
6
8
10
12
14
16
18
20
22
24
26
270
225
225
180
135
090
045
225
225

PLATE III

BIBLIOGRAPHY

1. O'Connor, J. F., LCdr. USNR — Practical Methods of Weather Analysis and Prognoses, NavAer 5(-110R-51, Off. of CNO, November 1952.

2. Brier, G. W. — Predicting the Occurrence of Wintertime Precipitation for Washington, D. C., Unpubl., December 1945.

3. Thompson, J. C. — A Numerical Method for Forecasting Rainfall in the Los Angeles Area, Monthly Weather Rev., Vol. 78, No. 7, pp. 113-124, July 1950.

4. George, J. J. — Forecasting Relationships Between Upper Level Flow and Surface Meteorological Processes, AFCRC Tech Report 53-28, August 1953.

5. U. S. Weather Bur. — Northern Hemisphere Daily Synoptic Weather Maps, Sea Level and 500 Mb. Charts, January 1949 to February 1950, July to December 1950.

6. Bur. of Aeronautics Project AROWA, US Navy — Height Change Charts, 500 Mb., January 1949 to February 1950, July to December 1950.

7. Ezekiel, M. — Methods of Correlation Analysis, J. Wiley and Sons, 1941.

8. Brooks, C. E. P. and Carruthers, N. — Handbook of Statistical Methods in Meteorology, Her Majesty's Stationery Office, 1953.

9. Wolff, P. M., LCdr. USN — The Behavior of 24 Hr. Height Change Patterns at 500 Mb., Unpubl.

10. Oliver, V. J. and Oliver, M. B. — A Method for Applying Tilted-Trough Theory to Synoptic Forecasting in the Mid-Troposphere, Bull. Am. Met. Soc., Vol. 34, No. 8, pp. 368-375, October 1953.

11. Ernst, F. W., Fox R. L., and Hutchison, H. E. — Verification of a Formula for the Growth of Troughs and Wedges, Bull. Am. Met. Soc., Vol. 34, No. 10, pp. 441-443, December 1953.

12. Mansueto, E. J., LCdr., USN — An Investigation of the Movement of the 24 Hr. Isallohyptic Centers at 700 Mb., MS Thesis, U. S. Naval Postgraduate School, 1949.

13. Berry, F. A., Capt., Haggard, W. H., LCdr., and Wolff, P. M., LCdr., USN — 500 Mb. Studies at Project AROWA, Bull. Am. Met. Soc., Vol. 34, No. 10, pp. 444-453, December 1953.

14. Hoel, P. G. — Introduction to Mathematical Statistics, J. Wiley and Sons, 1949.